

What is claimed is:

[Claim 1] A method for forming a passivated metal layer, the method comprising:
providing a substrate in a process chamber of a processing system;
exposing the substrate to a process gas containing a rhenium-carbonyl precursor to deposit a rhenium metal layer on the substrate in a thermal chemical vapor deposition process; and
forming a passivation layer on the rhenium metal layer, wherein the passivation layer is effective to inhibit oxygen-induced growth of Re-containing nodules on a surface of the rhenium metal layer.

[Claim 2] The method according to claim 1, wherein the rhenium carbonyl precursor comprises $\text{Re}_2(\text{CO})_{10}$.

[Claim 3] The method according to claim 1, wherein the passivation layer comprises a passivation metal layer containing W, Ru, Ti, Ta, Ni, Mo, Co, Rh, Re, Os, or Cr, or a combination of two or more thereof, formed by plasma-enhanced chemical vapor deposition, atomic layer deposition, or physical vapor deposition.

[Claim 4] The method according to claim 3, wherein the passivation layer further comprises a Si layer formed on the passivation metal layer.

[Claim 5] The method according to claim 3, wherein the passivation layer is a tungsten metal layer formed by thermal chemical vapor deposition from a tungsten-carbonyl precursor.

[Claim 6] The method according to claim 1, wherein the passivation layer comprises a metal-containing layer containing a metal silicide, a metal carbide, a metal nitride, a metal oxide, or a metal boride, or a combination of two or more thereof.

[Claim 7] The method according to claim 6, wherein the metal of the metal-containing layer is W, Ru, Ti, Ta, Ni, Mo, Co, Rh, Re, Os, or Cr, or a combination of two or more thereof.

[Claim 8] The method according to claim 1, wherein forming the passivation layer comprises exposing the metal layer to a gas containing silicon, carbon, nitrogen, oxygen, or boron, or a combination of two or more thereof, and annealing the

substrate to diffuse the respective silicon, carbon, nitrogen, oxygen or boron into the metal layer.

[Claim 9] The method according to claim 8, wherein the gas comprises SiH_4 , Si_2H_6 , SiCl_2H_2 , Si_2Cl_6 , CH_4 , C_2H_6 , C_2H_4 , C_2H_2 , C_3H_6 , $\text{C}_2\text{H}_5\text{OH}$, $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$, CH_3COCH_3 , $\text{C}_4\text{H}_8\text{O}$, N_2 , NH_3 , NO , NO_2 , N_2O , O_2 , BH_4 or B_2H_6 , or a combination of two or more thereof.

[Claim 10] The method according to claim 1, wherein forming the passivation layer comprises exposing the substrate to a metal-carbonyl precursor gas and a silicon-containing gas, a carbon-containing gas, a nitrogen-containing gas, an oxygen-containing gas, or a boron-containing gas, or a combination of two or more thereof, to form at least one of a metal silicide layer, a metal carbide layer, a metal nitride layer, a metal oxide layer, or a metal boride layer, or a combination thereof.

[Claim 11] The method according to claim 10, wherein the metal-carbonyl precursor comprises $\text{W}(\text{CO})_6$, $\text{Ru}_3(\text{CO})_{12}$, $\text{Ni}(\text{CO})_4$, $\text{Mo}(\text{CO})_6$, $\text{Co}_2(\text{CO})_8$, $\text{Rh}_4(\text{CO})_{12}$, $\text{Re}_2(\text{CO})_{10}$, $\text{Os}_3(\text{CO})_{12}$, or $\text{Cr}(\text{CO})_6$, or a combination of two or more thereof, the silicon-containing gas comprises SiH_4 , Si_2H_6 , SiCl_2H_2 , Si_2Cl_6 , or a combination of two or more thereof, the carbon-containing gas comprises CH_4 , C_2H_6 , C_2H_4 , C_2H_2 , C_3H_6 , $\text{C}_2\text{H}_5\text{OH}$, $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$, CH_3COCH_3 , or $\text{C}_4\text{H}_8\text{O}$, or a combination of two or more thereof, the nitrogen-containing gas comprises N_2 , NH_3 , NO , NO_2 , or N_2O , or a combination of two or more thereof, the oxygen-containing gas comprises O_2 , and the boron-containing gas comprises BH_4 or B_2H_6 , or both.

[Claim 12] The method according to claim 1, wherein the passivation layer comprises a silicon-containing layer or a carbon-containing layer formed on the metal layer.

[Claim 13] The method according to claim 1, wherein the metal layer and the passivation layer are formed in the same processing system.

[Claim 14] The method according to claim 1, wherein the metal layer and the passivation layer are formed in different processing systems.

[Claim 15] A method for forming a passivated Re layer, the method comprising:
providing a substrate in a process chamber of a processing system;

exposing the substrate to a process gas containing a $\text{Re}_2(\text{CO})_{10}$ precursor to deposit a Re layer on the substrate in a chemical vapor deposition process; and forming a passivation layer on the Re layer, wherein the passivation layer is effective to inhibit oxygen-induced growth of Re-containing nodules on a surface of the Re layer.

[Claim 16] The method according to claim 15, wherein the passivation layer comprises a W layer formed in a chemical vapor deposition process by exposing the Re layer to $\text{W}(\text{CO})_6$.

[Claim 17] The method according to claim 15, wherein the passivation layer comprises a silicon-containing layer formed in a chemical vapor deposition process by exposing the Re layer to SiH_4 , Si_2H_6 , SiCl_2H_2 , or Si_2Cl_6 , or a combination of two or more thereof.

[Claim 18] The method according to claim 15, wherein the Re layer and the passivation layer are formed in the same processing system.

[Claim 19] The method according to claim 15, wherein the Re layer and the passivation layer are formed in different processing systems.

[Claim 20] A computer readable medium containing program instructions for execution on a processor, which when executed by the processor, cause a processing tool to perform the steps of claim 1.